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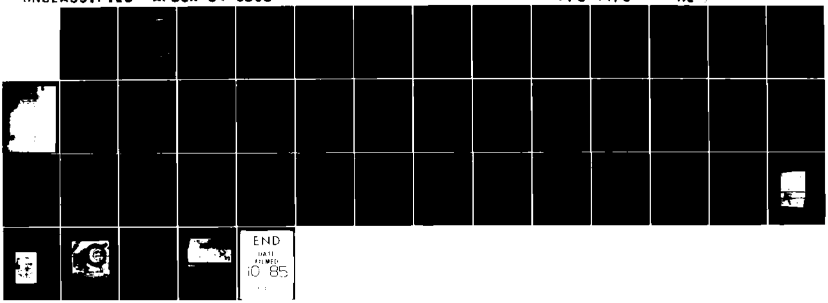

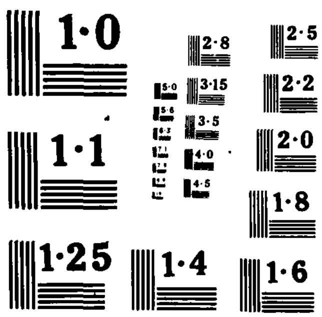
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Final report of US/Japan seminar discusses program and plant visits.

see attached

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20. Abstract

The US/Japan Seminar on Superalloys was held at Fuji Kyoiku Kemshusho, Susono, Japan on December 7-11, 1984. A delegation of fifteen US scientists and engineers, headed by Professors J. K. Tien of Columbia University and N. S. Stoloff of Rensselaer Polytechnic Institute, participated in the Seminar. The Japanese delegation of 59 persons was headed by Professors R. Tanaka and M. Kikuchi of Tokyo Institute of Technology. In addition, poster papers were presented by Professor Tien and by Dr R. Miner of NASA.

The scope of Japanese work on superalloys is comprehensive, with papers presented on the following subjects: alloy development, processing, mechanical properties, surface stability (oxidation and hot corrosion), phase stability and alternative materials (especially intermetallic compounds). These subjects represent a marked expansion of Japanese efforts on superalloys since the previous meeting in 1972.

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Final Report to AFOSR
Grant No. AFOSR-0262
Principal Investigator - N. S. Stoloff
US/Japan Seminar on Superalloys
December 7-11, 1984

The US/Japan Seminar on Superalloys was held at Fuji Kyoiku Kemshusho, Susono, Japan on Dec. 7-11, 1984. A delegation of fifteen US scientists and engineers, headed by Profs. J.K. Tien of Columbia University and N.S. Stoloff of Rensselaer Polytechnic Institute, participated in the Seminar. The Japanese delegation of 59 persons was headed by Profs. R. Tanaka and M. Kikuchi of Tokyo Institute of Technology. In addition, poster papers were presented by Prof. Tien and by Dr. R. Miner of NASA. A copy of the program, including fourteen papers presented as posters by the Japanese delegation is appended, together with a list of all delegates from both countries.

The seminar, which was a reciprocal visit to Japan for a similar meeting at Diamond Point, New York in 1972 was characterized by active discussion by both delegations, and an unusually detailed exposition of Japanese efforts in the superalloys field. Much of that effort stems from three national undertakings set out by the Japanese government in the fields of Energy Efficiency, (Moonlight Project), Nuclear Steelmaking and Research and Development Technology for Future Industries. The scope of Japanese work on superalloys is comprehensive, with papers presented on the following subjects: alloy development, processing, mechanical properties, surface stability (oxidation and hot corrosion), phase stability and alternative materials (especially intermetallic compounds). These subjects represent a marked expansion of Japanese efforts on superalloys since the previous meeting in 1972.

The formal seminar was supplemented by a series of plant and laboratory tours for the US delegation. The following sites were visited:

Dec. 12	Kawasaki Heavy Industries
Dec. 13	Mitsubishi Heavy Industries, Ltd (AM)
	Takasago Technical Institute
	Takasago Machinery Works
	Kobe Steel, (PM)
	Takasago Plant
Dec. 14	Ishikawajima-Harima Heavy Industries Co., Ltd (IHI)
	Mizuho Works
Dec. 15	National Research Institute for Metals (AM)

Turbine engine manufacturing and/or facilities were viewed at Kawasaki Heavy Industries and during the all-day visit to IHI. Extensive mechanical testing facilities were toured at Mitsubishi Heavy Industries - Takasago Technical Institute and at National Research Institute for Metals. At the end of each tour a discussion period was held between hosts and the US delegation. The plant trip confirmed our impression that Japanese government involvement in superalloys research is predominant.

JAPAN - U.S. SEMINAR ON SUPERALLOYS

Fuji Kyoiku Kenshusho, Susono, Japan
December 7-11, 1984

TENTATIVE PROGRAM

Saturday Morning, December 8

OPENING

R. Tanaka (Chairman of the Japanese Organizing Committee)

J. K. Tien (Chairman of the U.S. Delegation)

SESSION I ALLOY DESIGN, LONG RANGE ORDERED ALLOYS AND CERAMICS

NEW APPROACH TO THE DESIGN OF SUPERALLOYS
N. Yukawa, M. Morinaga (Toyohashi University of Technology)

STRENGTH AND PHASE STABILITY OF Ni_3Al INTERMETALLIC COMPOUNDS -TOWARD ALLOY DESIGN OF SUPERALLOYS-
Y. Mishima, T. Suzuki (Tokyo Institute of Technology)

ORDERED INTERMETALLIC ALLOYS FOR USES
C. T. Liu (Oak Ridge National Laboratory)

RECENT ADVANCES IN HIGH TEMPERATURE CERAMICS AND PORCELAIN
F. Lemkey (United Technologies Research Center)

Saturday Afternoon, December 8

SESSION II RESEARCH PROGRAMS

NASA SCIENTIFIC PROGRAMS ON SUPERALLOYS
R. V. Miner (National Aeronautics and Space Administration)

JAPANESE GOVERNMENT R & D PROGRAMS ON SUPERALLOYS
R. Tanaka (Tokyo Institute of Technology)

NICKEL-BASE SUPERALLOYS DEVELOPED FOR TWO RECENT NATIONAL PROJECTS IN JAPAN
M. Yamazaki (National Research Institute for Metals)

NAVY SCIENTIFIC PROGRAMS ON SUPERALLOYS
B. McDonald (U.S. Office of Naval Research)

AIR FORCE RESEARCH ON SUPERALLOYS
A. Rosenstein (U.S. Air Force Office of Scientific Research)

Saturday Evening, December 8

POSTER SESSION

Sunday Afternoon, December 9

SESSION III SUPERALLOYS FOR SMALL ENGINES AND INDUSTRIAL GAS TURBINES

PROBLEMS FOR SUPERALLOYS IN SMALL ENGINE APPLICATION
D. Ruckle (Garrett Turbine Engine)

SUPERALLOYS FOR LAND BASE GAS TURBINES IN JAPAN
I. Tsuji (Mitsubishi Heavy Industries)

~~CONSIDERATIONS OF MATERIAL STABILITY IN THE DESIGN~~ OF
~~INDUSTRIAL GAS TURBINE BLADES~~
~~E. A. Crombie, III (Westinghouse Electric)~~

HEAT-RESISTING STEELS FOR BOILER TUBINGS IN JAPAN
T. Yukitoshi (Sumitomo Metal Industries)

Monday Morning, December 10

SESSION IV CREEP AND FATIGUE AND PROCESSING I (HOT WORKING)

LONG-TERM CREEP-RUPTURE PROPERTIES OF SEVERAL COMMERCIAL SUPERALLOYS
S. Yokoi, Y. Monma (National Research Institute for Metals)

FATIGUE BEHAVIOR OF SUPERALLOYS
S. D. Antolovich (Georgia Institute of Technology)

HIGH TEMPERATURE FATIGUE OF SUPERALLOYS
M. Kitagawa (Ishikawajima-Harima Heavy Industries)

HOT WORKABILITY OF SUPERALLOYS
W. H. Couts, Jr. (Wyman-Gordon)

HOT DEFORMATION RESISTANCE OF Ni-BASE ALLOYS
M. Tamura (Nippon Kokan)

Monday Afternoon, December 10

SESSION V PROCESSING II (MELTING AND SOLIDIFICATION)

UNDERSTANDING VACUUM MELTING OF SUPERALLOYS
G. E. Maurer (Special Metals)

MONOCRYSTALLINE SUPERALLOYS -SCIENCE AND TECHNOLOGY-
M. Gell (Pratt & Whitney Aircraft)

DEVELOPMENT OF SOLIDIFICATION TECHNOLOGY FOR SUPERALLOYS IN JAPAN
Y. G. Nakagawa (Ishikawajima-Harima Heavy Industries)

SCIENCE AND TECHNOLOGY OF EUTECTIC SUPERALLOYS
N. S. Stoloff (Rensselaer Polytechnic Institute)

Monday Evening, December 10

SESSION VI ENVIRONMENTAL ENTERACTION

UNDERSTANDING HOT CORROSION RESISTANCE OF MULTICOMPONENT SUPERALLOYS
F. S. Pettit (University of Pittsburgh)

LATEST DEVELOPMENTS IN CORROSION RESISTANT WROUGHT SUPERALLOYS
D. R. Muzyka (Cabot)

~~RECENT ADVANCES IN SURFACE PROTECT~~ION
~~D. H. Boone (Lawrence Berkeley National Laborator~~ies)

MECHANICAL PROPERTIES AND CORROSION OF SUPERALLOYS IN HIGH TEMPERATURE HELIUM ENVIRONMENT
T. Kondo (Japan Atomic Energy Research Institute)

EFFECTS OF HYDROGEN ON SUPERALLOY PROPERTIES
R. Jewett (Rocketdyne Division of Rockwell International)

Tuesday Morning, December 11

SESSION VII PROCESSING III (POWDER METALLURGY)

PRODUCTION METHODS OF SUPERALLOY POWDERS
T. Kato, K. Kusaka, A. Horata (Daido Steel)

DEVELOPMENT OF POWDER METALLURGY FOR SUPERALLOYS IN JAPAN
S. Ohta (Kobe Steel)

THE SCIENCE AND TECHNOLOGY OF ODS AND P/M SUPERALLOYS
J. K. Tien (Columbia University)

SUMMARY TALKS AND CLOSING ADDRESS

P-J1 PHASE EQUILIBRIA IN Ni-Cr-W-C QUATERNARY SYSTEM AT LOW CARBON ACTIVITY AT 1,100°C
M. Kajihara, H. Usuki, M. Kikuchi, R. Tanaka (Tokyo Institute of Technology)

P-J2 PRECIPITATION OF CARBIDES AND ALPHA-TUNGSTEN IN Ni-Cr-W SUPERALLOYS AT 1,000°C
F. Abe, T. Tanabe (National Research Institute for Metals)

P-J3 EFFECT OF GRAIN SIZE ON HIGH TEMPERATURE CREEP PROPERTIES OF A Ni-20Cr-20W ALLOY
T. Matsuo, R. Tanaka (Tokyo Institute of Technology)

P-J4 EFFECTS OF CARBON AND BORON ON HIGH TEMPERATURE CREEP PROPERTIES OF Ni-20Cr-20W ALLOYS
M. Takeyama, T. Matsuo, R. Tanaka (Tokyo Institute of Technology)

P-J5 CREEP-FATIGUE BEHAVIOR OF Ni-Cr-W ALLOYS FOR HIGH TEMPERATURE GAS-COOLED REACTOR
K. Furuya, T. Kainuma (National Research Institute for Metals)

P-J6 CORROSION CHARACTERISTICS OF Ni-BASE SUPERALLOYS IN HELIUM ENVIRONMENT
A. Hiromoto, T. Daikoku, H. Kinoshita, T. Matsumoto (Mitsubishi Heavy Industries)

P-J7 STRENGTH PROPERTIES OF A NICKEL-BASE SUPERALLOY SUBJECT TO CREEP-FATIGUE INTERACTION IN HOT CORROSIVE ENVIRONMENT
M. Yoshiba, O. Miyagawa (Tokyo Metropolitan University)

P-J8 ROLE OF TRANSITION ELEMENTS ON THE MC-CARBIDE FORMATION IN IN-100
Y. Murata, K. Suga, N. Yukawa (Toyohashi University of Technology)

P-J9 SINGLE CRYSTAL CASTING THROUGH LIQUID METAL COOLING
S. Isobe (Daido Steel)

P-J10 DEVELOPMENT OF DIRECTIONALLY SOLIDIFIED AND SINGLE CRYSTAL TURBINE BLADES FOR INDUSTRIAL GAS TURBINE ENGINES IN KAWASAKI HEAVY INDUSTRIES
S. Tanaka, T. Suemitsu, J. Fujioka, Y. Nishiyama (Kawasaki Heavy Industries)

P-J11 MICROSTRUCTURE AND SUPERPLASTICITY OF MELT-SPUN SUPERALLOY RIBBONS
K. Yasuda, M. Tsuchiya, T. Kuroda, M. Suwa (Hitachi)

P-J12 ISOTHERMAL FORGING OF P/M SUPERALLOY
N. Kawai, T. Matsushita, H. Takigawa, K. Iwai (Kobe Steel)

P-J13 TLP BONDING FOR HEAT RESISTANT ALLOY MAR M-247
M. Nakahashi, H. Takeda, K. Shimotori (Toshiba)

P-J14 WELDING OF Ni-BASE SUPERALLOYS
Y. Nakao (Osaka University)

JAPAN - U.S. SEMINAR ON SUPERALLOYS

Members of U.S. Delegation

Antolovich, Steven D.	Georgia Institute of Technology
~~Boone, Donald H.~~	~~Lawrence Berkeley National Laboratories~~
Couts, Wilford H., Jr.	Wyman-Gordon
Gell, Maurice	Pratt & Whitney Aircraft
Jewett, Robert	Rocketdyne Division of Rockwell International
Lemkey, Franklin	United Technologies Research Center
Liu, Chain T.	Oak Ridge National Laboratory
MacDonald, Bruce	U.S. Office of Naval Research
Maurer, Gernant E.	Special Metals
Miner, Robert V.	U.S. National Aeronautics and Space Administration
Muzyka, Donald R.	Cabot
Pettit, Frederick S.	University of Pittsburgh
Rosenstein, Alan	U.S. Air Force Office of Scientific Research
Ruckle, Duane	Garrett Turbine Engine
Stoloff, Norman S.	Rensselaer Polytechnic Institute (U.S. Delegation Co-Chairman)
Tien, John K.	Columbia University (U.S. Delegation Chairman)

<u>List of Japanese Participants</u>

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Daido Steel, Central Research Laboratory	Kusaka, Katsushi
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Hitachi Metals, Metallurgical Laboratory	Watanabe, Rikizo
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IHI, Research Institute	Kitagawa, Masaki
IHI, Research Institute	Nakagawa, Yukiya G.
IHI, Research Institute	Ohtomo, Akira
IHI, Research Institute	Saiga, Yoshinori
Japan Atomic Energy Research Institute	Kondo, Tatsuo
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Kawasaki Heavy Industries, Technical Institute	Fujioka, Junzo
Kawasaki Heavy Industries, Technical Institute	Nishiyama, Yukio
Kawasaki Heavy Industries, Technical Institute	Tanaka, Shoji
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Kobe Steel, Central Research Laboratory	Kawai, Nobuyasu
Kobe Steel, Central Research Laboratory	Ohta, Sadao
Komatsu, Technical Research Center	Miyahara, Yutaka
Mecahnical Engineering Laboratory	Nakazawa, Yoshinori
Meisei University	Ishii, Tomoyuki
Mitsubishi Heavy Industries, Nagasaki Technical Institute	Hiromoto, Akira
Mitsubishi Heavy Industries, Takasago Technical Institute	Susukida, Hiroshi
Mitsubishi Heavy Industries, Takasago Technical Institute	Tsuji, Ichiro
Mitsubishi Metal, Okegawa Alloy Products Plant	Kurauchi, Nobuyoshi
Mitsubishi Metal, Central Research Institute	Ohe, Junya
National Defense Academy	Kondo, Yoshihiro
National Research Institute for Metals	Abe, Fujio
National Research Institute for Metals	Furuya, Kazuo
National Research Institute for Metals	Monma, Yoshio
National Research Institute for Metals	Yamazaki, Michio
Nippon Kokan, Technical Research Center	Ozeki, Akichika
Nippon Kokan, Technical Research Center	Tamura, Manabu
Nippon Metal Industry, Research Laboratory	Takeda, Seiichi

Nippon Steel, R & D Laboratories - II	Kikuchi, Masao
Nippon Steel, R & D Laboratories - II	Sakakibara, Mizuo
Nippon Steel, R & D Laboratories - I	Suzuki, Hirowo G.
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Sumitomo Metal Industries, Central Research Laboratory	Yukitoshi, Teruo
Sumitomo Metal Mining, Central Research Laboratory	Achikita, Masakazu
Tohoku University	Suto, Hajime
Tokyo Institute of Technology	Kajihara, Masanori
Tokyo Institute of Technology	Kikuchi, Makoto
Tokyo Institute of Technology	Matsuo, Takashi
Tokyo Institute of Technology	Mishima, Yoshinao
Tokyo Institute of Technology	Takeyama, Masao
Tokyo Institute of Technology	Tanaka, Ryohei
Tokyo Metropolitan University	Miyagawa, Ohmi
Tokyo Metropolitan University	Yoshiba, Masayuki
Toshiba, Toshiba R & D Center	Nakahashi, Masako
Toshiba, Yokohama Metals Works	Shimotori, Kazumi
Toyo Soda Manufacturing, Yamagata Works	Tanaka, Yoshio
Toyohashi University of Technology	Murata, Yoshinori
Toyohashi University of Technology	Yukawa, Natsuo
Toyota Central Research and Development Laboratories	Nishino, Kazuaki
Toyota Central Research and Development Laboratories	Obayashi, Mikio

Saturday Evening, December 8, 7:00-10:00 pm

POSTER SESSION

PAPER

P-J1 PHASE EQUILIBRIA IN Ni-Cr-W-C QUATERNARY SYSTEM AT LOW CARBON ACTIVITY AT 1,100°C
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S. Tanaka, T. Suemitsu, [illegible] Fujioka, Y. [illegible] (Kawasaki Heavy Industries)

chemistries. Turbine vanes and blades are vacuum remelted and investment cast from VIM ingots. VIM ingots are also the electrodes for vacuum arc remelting (VAR), which refines the macrostructure of the superalloys that will be hot worked. The VAR ingots are rolled down to billet or bar stocks. Billets are cut and forged into the heavy section turbine disks, upon which the turbine blades sit. Bar stock are used for hot pressed or forged blades and for fastener hardware. Sheet superalloys are rolled from billet stock and are used for the combustor (burner can) sections and exhaust piping. Hard to forge, high strength, wrought alloys are first vacuum atomized, and the resultant fine grained consolidates are then more easily hot worked. A small amount of as-consolidated, usually hot isostatically pressed (HIP), near-net-shape turbine hardware are also produced.

In the United States over the past 30 years, the superalloys industry developed in a highly free-enterprise and non-integrated fashion. There are four to five major primary producers, (one specializing in sheet alloys), which VIM and break down the wrought alloys. A couple of these also produce powder (P/M) superalloys. These primary producers are either small companies or smaller

successful, a phase II turbine with a turbine inlet temperature of 1500°C will be designed. This turbine's materials requirements will exceed current superalloys capabilities. New Japanese superalloys (Table I) are under de-v lopment; so too is the use in landbased gas turbines of such jet engine technology as advanced blade film cooling and segmented wafer blade technology.

Production at the leading Japanese jet engine and gas turbine manufacturers is well supported by design, engineering, and component and engine testing, as well as materials research and development laboratories. CAD is common, and U.S. heat transfer and stress analysis codes have been absorbed and adapted for Japanese use. Component and especially engine test facilities are plentiful and modern.

SUPERALLOYS

Jet engine and/or gas turbine rated superalloy production all begins with vacuum induction melting (VIM), which alloys and refines the multicomponent

turbine producers as are Kobe Steel, Mitsui, Niigata, Hitachi, and Toshiba. Nearly all the larger capacity gas turbines are also produced under (mostly) United States license in these companies. However, there are strong indications that Japan is making progress in developing its own proprietary land-based turbines, so that it will gradually pull free of the limiting state of production under license and start the production of its own models, using Japanese superalloys.

One of the more costly national (government funded) projects in Japan is also aimed at eventually ensuring Japanese independence in gas turbine technology, production, and sales. Now into its sixth year, this project is named "Moonlight," and is concerned with the development of energy saving technology including advanced reheat and fuel efficient (high temperature) gas turbines. The gas turbine portion of the project includes in its first phase the design, construction, and testing of a reheat gas turbine with turbine inlet temperature of 1300°C and a combined cycle efficiency of 50 percent when coupled with a steam turbine. This experimental turbine, entirely made with all U.S. superalloys and known as AGTJ-100A, will undergo engine tests in 1985. If

production and sale of the larger electric utility peak-load, 100 MW or larger gas turbines.

Mitsubishi Heavy Industries is Japan's leading stationary gas turbine manufacturer. Its gas turbine division, located at the Takasago Machinery Works, is sometimes irreverently known as Eastinghouse. In 1961, Mitsubishi established a series of licensed production agreements with U.S.'s Westinghouse Electric Corporation, which, with GE, is among the world's premier landbased gas turbine manufacturers. Since then Mitsubishi has produced about 4,000 MW worth of gas turbines. About 20 percent of the larger units were exported, competing directly with the licensor everywhere except in the United States, and the rest are meeting most of the peak electric power demands of Japan, as well as serving large industrial complexes as direct peak power and emergency power units. Through the years, Westinghouse has transferred to Mitsubishi first its 10 MW, then its 20 MW and 40 MW units. Lately, Mitsubishi has also been licensed to produce the advanced 100 and 120 MW units (MW 501 and MW 701) (Fig. 3).

Japan's other two jet engine producers, IHI and Kawasaki, are also major gas

the guiding spirit for Japan's no-layoff policy, worker loyalty, and general goodwill between workers and management in the country's leading industries.

GAS TURBINES

The future of Japan's landbased gas turbine industry is brighter. This was preordained by the government regulation that every building in Japan bigger than a certain size must have an emergency electricity generating set. By last year gas turbines shared equally in this market with diesel and gasoline engine generators. It is not surprising, then, that Japan is the leading producer of gas turbines, accounting for one-third of the world's production. Two-thirds of Japan's units are small generator sets (less than 999 PS rating) produced for domestic use. In terms of power output, the Japanese production accounted for only 5 percent of the world's production whose units had a combined total rating of about 10,000 MW (3,4).

Since material use, including superalloy content, in gas turbines is directly related to size and thus to the MW output the key question is the status of

five interacting parties--Rolls-Royce, West Germany's MTU, Pratt & Whitney Aircraft, Italy's Fiat, and Japan (Fig. 2). The 2 in the 2500 is suspiciously similar to the 2 with which P&WA begins the designation of its current crop of turbofans. Indeed, the design of the critical and superalloys containing hot section (the first stages of the turbine vane, blade, and disks after the combustor) is mostly the responsibility of P&WA. Japan is literally left out in the cold in this joint project, on which it had depended to advance and use its superalloys capabilities.

It should be noted that, although Ishikawajima Harima Heavy Industries (IHI) is Japan's leading jet engine manufacturer, its competitors, Mitsubishi Heavy Industries and Kawasaki, are also directly involved as partners or vendors in the same licensed production, FJR, RJ500, or V2500 projects. This often practiced pro-trust collaboration among competitors is one of the fundamental differences between market-economy Japan and the market-economy but anti-trust minded United States (2). Known as one of the "Japanese ways," this behavior is traditionally confucian and meant to enhance harmony and mutual help and survival. The one-house-under-the-same- heaven philosophy, of course, is also

Recognizing the limitations imposed by licensing agreements, very limited domestic military demands, and refusal to sell arms, the Japanese government with full cooperation of the industrial sector went into a crash program starting in the late 1960's to develop a strictly Japanese medium-sized, 14,000 lb thrust turbofan engine for commercial aircraft. Fifteen years later, the resulting engine (known as FJR710) has gone through the engine test sequences and been found wanting. It is unusually heavy and with less than efficient thrust-to-weight ratio. The fate of the FJR710 (Fig. 1) is to be the power plant of a medium-sized short takeoff aircraft, which is also reputed to be a development failure.

By 1980, perhaps recognizing that it still needed help in the design of a new engine, including the innovations required to meet fuel-savings design goals, Japan entered into a joint venture with the U.K.'s Rolls-Royce Aeroengines. The result--a 20,000 lb. RJ500 turbofan engine--was targeted as the power plant for the predicted to be lucrative 150 seater, wide body airliner market. The RJ500 project has now been expanded into the V2500 engine project. The V denotes the

Although abounding in contemporary technology, Japanese jet engine production has remained at low levels. In 1983, the total production of flight engines was only about 2.5 percent (by unit) of world production. The growth of this industry is restrained by the licensing constraints, a ceiling for domestic defense demands, and a pacifist foreign policy.

As mentioned, for all practical purposes, Japanese manufactured jet engines are licensed productions for the fighter planes (whose manufacture is also licensed) of the Japanese defense forces. Stressing defense and an almost constitutional fear of reviving militarization, Japanese defense spending is and can be no more than 1 percent of the national budget. By contrast, the U.S. defense budget is roughly one-third of the total budget (not including debt service). Even if the licensing agreements permit, the Japanese engine manufacturers will find it difficult to export military engines to third world countries. In contrast to the USSR, USA, China, Europe, and just about every country that can produce arms at a profit, Japan has refrained from selling arms. This laudable stance, at least for the present, is ingrained in the industrial culture of Japan.

The first of several events that put Japan permanently in the advanced jet engine business occurred in 1960 when it selected the then advanced F4 supersonic Phantom as the front line fighter for its small air (defense) force. Japan shrewdly coupled this selection with the condition that it be allowed to lessen the import burden and, at the same time, capture technology by the licensed production of much of the aircraft and components, including the engine. So it came to pass that U.S.'s General Electric Company (GE) transferred the technology to build the 17,000 lb. thrust J79 jet engine to Japan--afterburner and all. More then 600 units later, the other U.S. engine manufacturing giant, Pratt & Whitney Aircraft, transferred the technology of its very advanced 23,000 lb. thrust F100 turbofan engine to Japan as part-and-parcel of Japan's choosing, along with the United States, the F15 Eagle to replace the F4 as its mainstay fighter. During these years Japan also tasted Rolls-Royce engine technology by the licensed manufacture of the TF40 turbofan engine. Another boost to Japan's now world-class jet engine technology was the U.S. Federal Aviation Administration's granting certificates for engine repair and rebuilt stations in Japan.

strength to high temperatures. At present, the United States rules supreme in the research, development, and production of these alloys, which are used mainly in the hot turbine sections of jet engines and stationary gas turbines (1). Japan, or at least its formidable and pervasive Ministry of International Trade and Industry (note the order of listing), has recently voiced Japan's ambition to become a world leader in the manufacturing of jet engines and landbased gas turbines, and by necessity, superalloys.

JET ENGINES

To understand the limitations on growth of Japan's superalloys industry, it is is first necessary to understand its jet engine and gas turbine industries. In 1945, Japan produced one of the world's first jet engines--long before the United States did so. However, the war ended before this engine, the Ne22, saw combat. It was then transformed into the low-thrust, comparatively low technology J3 engine and produced in limited quantities to power a few squadrons of Japanese trainers and patrol aircraft.

Taiwan, Brazil, and Spain have been successfully nipping away at the lower technology, but massive output end of the Japanese mineral empire. When the returns are in for 1984, the large Japanese integrated steel giants are expected yet again to break even, but just barely since they are operating at as low as 60 percent of capacity. Recovery of the basic mineral industry in Japan--and in the United States--is not expected to result in significant profitability even after the current lengthy mineral depression is over. Korea, Brazil, Taiwan, and others have already added new and productive basic iron and steel capacity and stand ready to challenge during the next mineral business upswing. Recognizing the threats from these countries at the low end, the Japanese aim to climb up the mineral technology and added-value ladder--mostly at the expense of the United States. Already they are competing well in the alloy steel, stainless steel, tool steel, magnetic steel, and titanium markets.

The top-of-the-line (at about $10 to $50 a pound) structural metallic system is the critical and strategic superalloys. These vacuum melted, multicomponent alloys are "super" because they are heat resistant and maintain reasonable

Japan, being chased up the mineral technology ladder by the emerging industrialized nations, is challenging the United States for control of this last bastion of American mineral technology. Can Japan do it? How soon? This article assesses Japan's jet engine, gas turbine, and superalloys industries, and concludes that there are many constraints that will dampen their growth.

INTRODUCTION

Pride, competitiveness, productivity, gutsy capitalization, and industry-friendly government interference have made Japan a leader in many market sectors. During the past two decades, Japan has outwatched the Swiss, cannoned the Leica, made Sony a household word, and forced Detroit to its knees, screaming for import restrictions and begging for joint ventures. In the mineral resource sector, Big Steel is no longer synonymous with USS by the Monongahela, but with Nippon Kokan by Tokyo Bay. Kobe, Kawasaki, Mitsubishi Metals, Sumitomo, and other ferrous and nonferrous giants are as visible as Bethlehem, J&L, Republic, ALCOA, and TIMET. However, hunger for growth is universal, and newly industrialized and aggressive nations like South Korea,

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"LIMITS TO GROWTH OF

THE JAPANESE JET ENGINE AND SUPERALLOYS INDUSTRIES"

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In Italics

The United States leads the world in the production of jet engines and land-based gas turbines. It is also the major producer and excels in the science and technology of superalloys, which find critical applications in the hot turbine sections of these strategic and economically cricital power plants.

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cost-centers of larger corporations. The disk forgers form the next group of companies. There are three larger ones and a number of smaller ones. A host of vacuum investment casters compete in the superalloy arena, with a couple possessing superior technology including precision casting, directional solidification facilities and the capability of producing the fabled monocrystalline turbine blades. Lastly, of course, are the final customers—the jet engine and gas turbine producers. These are invariably multi-billion dollar corporations. The interested reader is referred to reference (1) for details on the United States superalloy industry.

In Japan, the situation is much different. The superalloys-related companies are almost all parts of large and well-capitalized corporations, and many resulted from backward integration of the jet engine and/or gas turbine manufacturers. IHI investment casts its own vanes and blades, including directionally solidified blades (by license). Mitsubishi, through its steel and metals divisions, investment casts, presses and forges, and has the capability of VIM melting and refining superalloys. It is probably the world's first and only nearly integrated superalloys/jet engine/gas turbine unit. In contrast to

the United States, many of Japan's leading iron and steel giants can and are VIM producing superalloys and can hot work the wrought alloys. These include Nippon Kokan, Kobe, and Daido. International conglomerates like Hitachi Metals are also in the superalloys business, as are ventures and joint ventures (with Japanese companies) of The International Nickel Company, Cabot Corporation, and Howmet Corporation.

Never have so many competed for so little. The total annual production of superalloys in Japan was estimated to be under 10 million lbs. in 1983 (3), over half of which comprised such simpler superalloys as Inconel 700, X-750, and even 800 and 600 series alloys foı nuclear reactor, petrochemical plant, and automobile (turbocharger) applications. United States production of superalloys is estimated to be 50 to 80 million lbs. a year. VIM ingots of almost all the turbine vane and blade alloys, e.g., Mar M247, Mar M200, and IN 738, for Japan's jet engines and gas turbines are produced in the United States. Much of the billets for wrought disks and blades, such as Udimet 720, Udimet 710, Waspaloy and IN 718 are also imported from the United States and Europe. This significant dependence on imports in no way reflects on Japanese capabil-

ity, but is the consequence of licensing agreements and the denial of license to produce alloys or even components.

Freedom from external constraints will start to occur upon the successful development of self-proprietary units. In terms of jet engines, Japan's own FJR 710, as it stands now, is a dud. Besides, it contains only U.S. superalloys. The V2500 engine, when and if successfully developed, will again most likely contain mainly advanced U.S. superalloys, whose production may be restricted. Thus far, Japan's larger landbased gas turbines are licensed units from GE and Westinghouse. The superalloys used are again U.S. produced, although the fabrication processes, including pressing and forging are being transferred to Japan. Japan's developing "Moonlight" turbines will initially contain only U.S. superalloys.

CAPABILITIES

The growth of the Japanese superalloys industry will not be limited by the state of superalloy science and technology in Japan. This fact became evident

during the TMS-JSM sponsored US-Japan Superalloys Seminar held at Mt. Fuji, Japan, in December 1984 (Fig. 4). The seminar, financially helped by the U.S. Air Force Office of Scientific Research and Japanese industries, also included comprehensive plant tours of key Japanese jet engine, gas turbine, and superalloy production and research facilities. Owing to recent changes in government policy, MITI sponsored research, including most of the materials results from the national projects, are open to public inquiry. Under the new policy, symposiums and international research forums--the US-Japan Superalloys Seminar being one of the first--will be held to accelerate the exchange of views and information. This departure from the usual Japanese policy of extreme discretion is a fallout of the recent pressures placed on Japan by the United States with respect to the whole spectrum of issues involving traditional Japanese intransigence towards importing foreign goods and exporting or exchanging information. Ironically, whereas the Japanese are learning to be candid and open to frank exchanges, the Americans during the conference were properly inscrutable, regulated by the myriad control of information export regulations recently imposed by the U.S. government even on the 30-year old superalloys technology.

As mentioned, development of new superalloys is one of the long-lead time tasks in the national Moonlight project. High temperature structural alloys are generally a high priority preoccupation of the Japanese government. The R&D Institute of Metals and Composites for Future Industries was established in 1981 to fund and promote R&D of "Advanced Alloys with Controlled Crystalline Structures" and "Advanced Composite Materials." These topics are also among those receiving special attention in the United States as the performance and reliability demands of jet engines and landbased gas turbines exceed the heat resistant properties offered by the traditional superalloys. In addition to the well-equipped industrial laboratories, Japan's National Research Institute for Metals deserves special mention as a national resource for leadership in high temperature structural materials research.

In terms of specific projects, the Japanese take the more productive approach of ranking priorities, making the hard decisions, and then placing resources and efforts on a few significant and relevant projects instead of spreading thin over the entire spectrum of possible research areas. In addition, the

policy of congeniality and cooperation even between rival companies ensures non-duplication of effort. A good example of this is the on-going research in superalloys atomization. Kobe Steel apparently is pilot planting and improving the now traditional argon atomization technique. IHI is working on the rotating electrode technique, which provides cleaner powder necessary for future higher performance applications, but is not optimum in terms of powder size distribution. NRIM is into the production of extremely fine powders, as is Daido Steel and Hitachi Metals.

Whereas P/M research ensures by one route the future development of advanced turbine disk superalloy materials, controlled structures and non-precipitation strengthened concepts are necessary to guide the development of material for future turbine vanes and blade applications. Japan already has monocrystalline alloy technology. Indeed, IHI has an operating pilot plant that awaits only an improved licensing climate or death of the patents to replicate itself into production units. The high temperature oxide dispersion strengthened alloys, still awaiting significant commercialization in the United States, have also been targeted in Japan for concentrated processing, alloy design and properties

research. High temperature ceramics--a British concept on which the United States had worked and discarded in the late 1970's, then revived last year--have been sufficiently developed by the Japanese to become turbine wheels in automotive turbochargers.

Japanese research institutions also concentrate on the less glamorous but very important side of superalloys research. Alloys are well characterized in terms of temperature and long time effects on mechanical properties (NMIR). Reliability research includes very comprehensive fracture mechanics evaluations of contemporary and newly designed superalloys (IHI). Hot workability is determined and understood on the specimen level as well as on the instrumented strain rate and temperature and multiaxial loading level (Nippon Kokan). Instrumentation, testing equipment, processing equipment, pilot-plant and plant constructions are not problems in Japan. Many of the self-same industries that produce and work on high temperature alloys are also equipment and processing plant contractors.

Funds, focused research, and modern facilities aside, Japan's strength lies

in its science and technology personnel. Almost without exception, they are competent and well rounded. Exceptional creativity shone in many, as well as a growing sense of frustration. They are deservedly proud of Japan's having so rapidly caught up with the United States in superalloy science and technology. Although their country has yet to innovate and lead in this materials area, they are confident that it can and will do so. However, frustration enters in that they are aware that Japanese innovations, like new alloys or processes, will not be accepted in the licensed engines. Even Japan's own developing engines are still pivoting about foreign materials owing to conservative management attitudes.

CONCLUDING REMARKS

Over the past decade, Japan has mastered the complex and exacting science and technology of jet engines, gas turbines, and the heat resistant superalloys so critical for these power plants. However, because of the constraints resulting from a growth almost entirely controlled through licensed production of mainly U.S. jet engines for Japanese air force consumption, and given its small

defense force and national policy not to export arms, Japan's jet engine industry is vest-pocket sized and may remain so. Its landbased utility gas turbine industry is thriving by comparison and may expand to include much of the U.S. production of gas turbines if U.S. manufacturers continue to license and transfer the production of the larger units to Japan. However, the total amount of superalloys that would go into power generation gas turbines is estimated to be only 5 to 10 million pounds, as opposed to 6 to 7 times that amount in jet engines (1).

Even if and when Japan becomes master-of-its-own-destiny in engine and/or turbine production, increasing its production of superalloys may not be easy to achieve. Superalloys themselves, as well as their processing technology, are often protected by either patents or proprietary knowledge, or both. It seems likely, therefore, that Japan's superalloy production will remain at about 5000 tons, with much of this being alloys for its nuclear, petrochemical, and automotive industries. Growth will be more likely in the metal processing areas like investment casting and hot forging of superalloys imported from the United States and Europe.

It should be noted that the price advantage Japan has traditionally enjoyed because of productive labor and up-to-date manufacturing plants may not be applicable to superalloys. Superalloys are constitutionally complex alloys with significant amounts of such elements as nickel, chromium, cobalt, and the refractory metals; these elements are not available in Japan or in the United States. Accordingly, as in the United States, the price of the superalloys produced in Japan is, and will continue to be, pegged to the cost of the imported alloying elements, leaving little room for either country to gain a price advantage. Of course, Japanese industries can enjoy a larger role in superalloys by acquiring U.S. companies (one such attempt recently failed (1)). The situation may also change if the U.S. superalloys industry, owing to its overcapacity, increasing under-capitalization, and sales-unfriendly government regulations, becomes unstable and undependable. In that case, there is little doubt that Japan has the capital, capacity, and intellectual resources to become the free world's primary producer of high temperature structural alloys.

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It is acknowledged that Waspaloy, Udimet, Mar M, Inconel, and IN are trademarks and designations of United Technologies Corporation, Special Metals Corporation, Martin Marietta Corporation, and the International Nickel Family of Companies.

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JOM Editor: Please use same photo of Tien that appeared in the Tien and Nardone article, September 1984 Issue of JOM.

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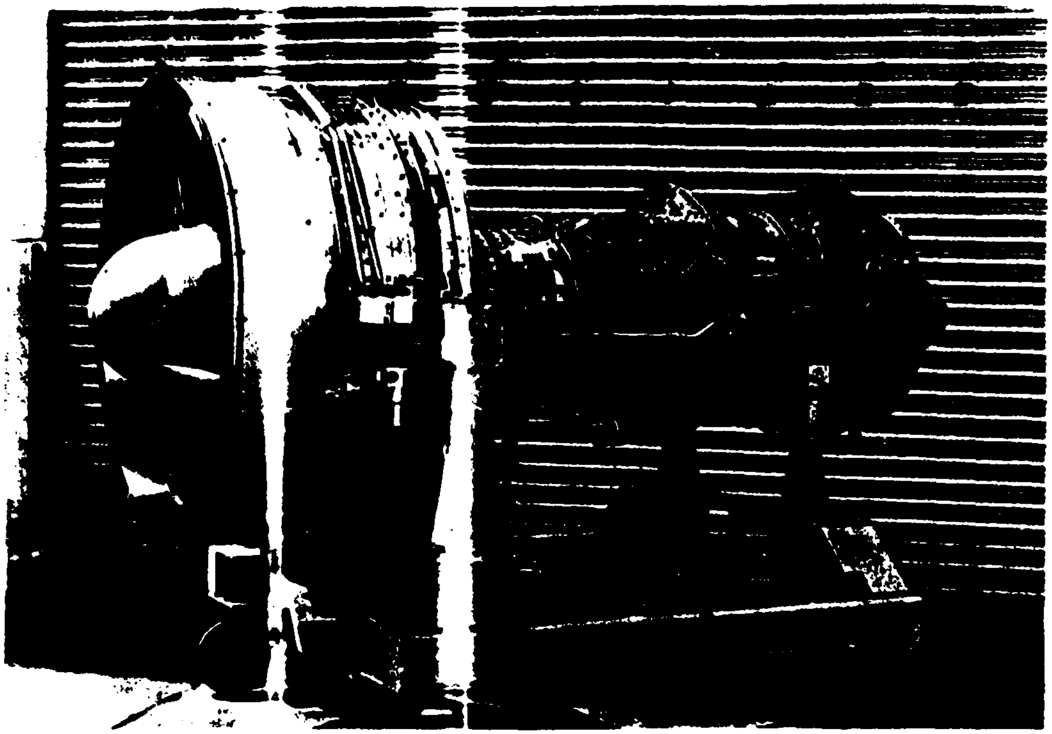

Fig. 1. Japan's own 14,000 lbs. thrust (experimental) medium cruising range turbofan engine (from IHI brochure). See text for discussion.

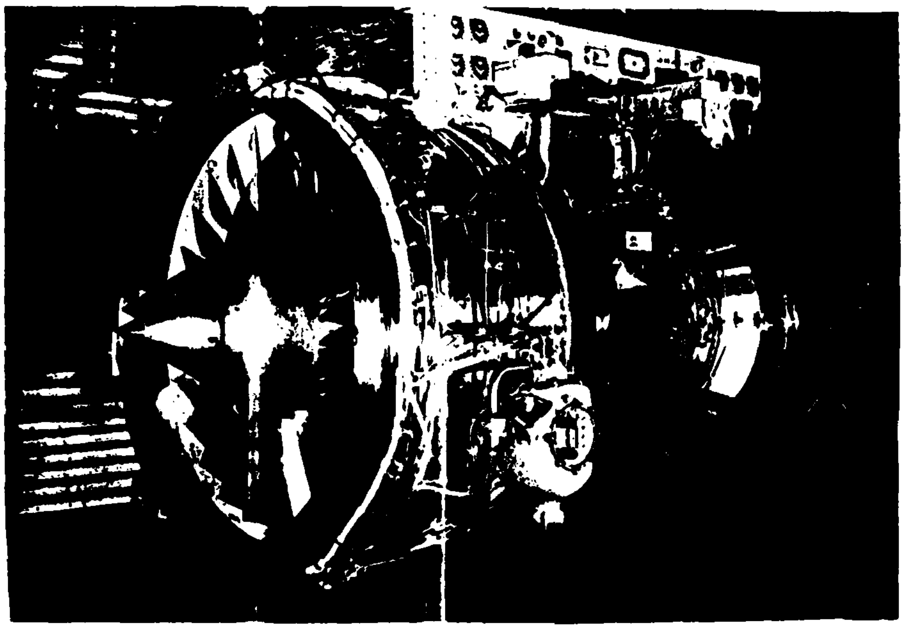

Fig. 2. The RJ500 is a 20,000 lbs. thrust class turbofan engine developed for 150-seater. under a joing project by Rolls-Royce Aeroengines and a consortium of three Japanese aerospace companies. This project has been expanded into the five-nation collaborative V2500 engine project, with the added participation of America's P&WA, West Germany's MTU, and Italy's Fiat. (From IHI brochure.)

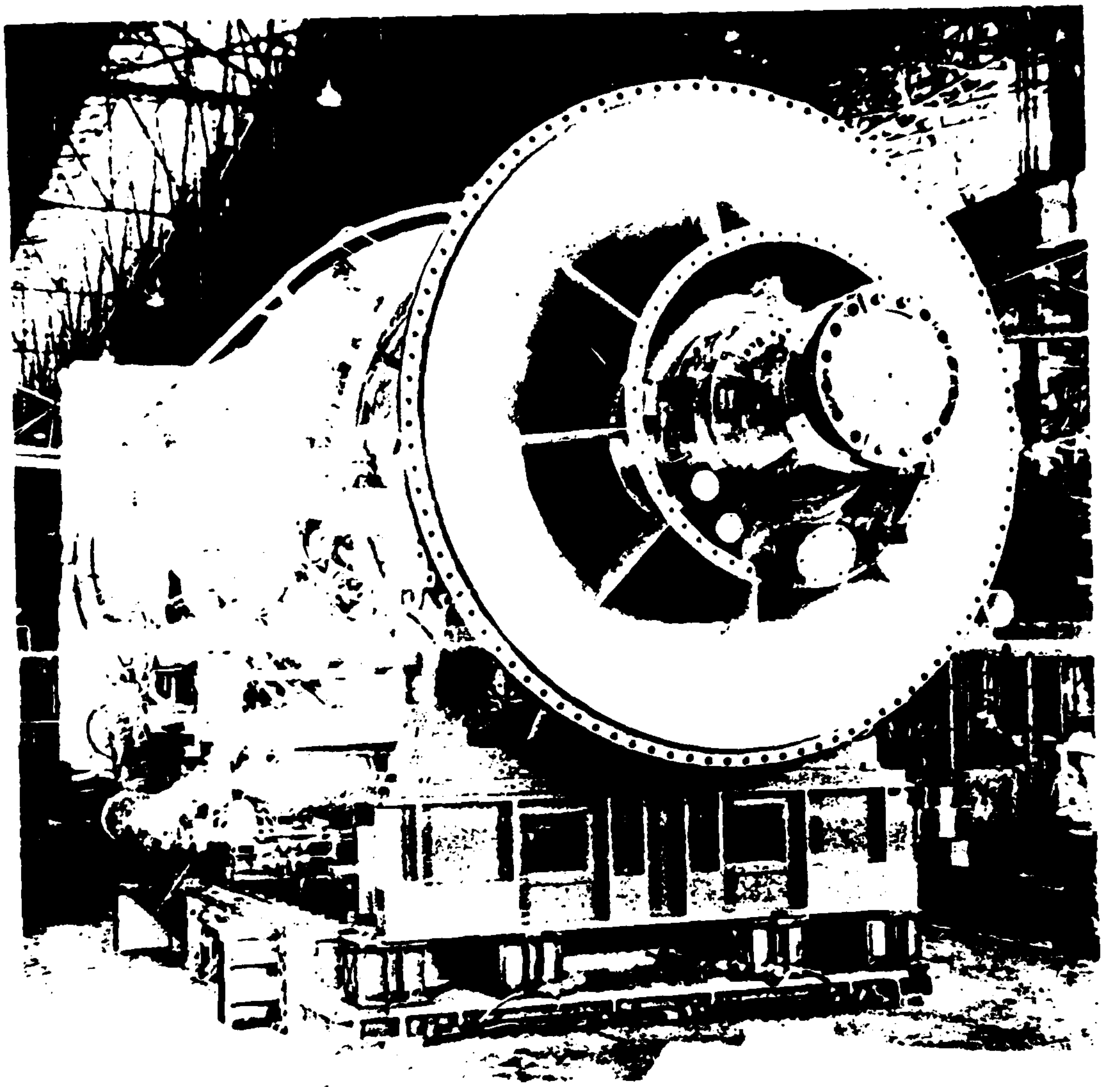

Fig. 3. Licensed production by Mitsubishi of 120 MW Westinghouse Landbased Gas Turbine. (From Mitsubishi brochure.)

TABLE I[3]

Examples of Superalloys
Recently Developed in Japan

Alloy	Chemical Composition wt. %												Application	Developer
	C	Cr	Co	Mo	W	Ti	Al	Ta	Hf	Zr	B	Ni		
TM-321	0.11	8.1	8.2	-	12.6	0.8	5.0	4.7	0.9	0.05	0.01	Bal.	Blade	NRIM
TM-269	0.11	9.7	8.9	-	13.2	0.6	4.3	3.8	0.8	0.05	0.01	Bal.	Nozzle	NRIM
TMD-5	0.07	5.8	9.5	1.9	13.7	0.9	4.6	3.3	1.4	0.015	0.015	Bal.	Blade for D.S.	NRIM
Rikiloy 4123	0.10	15.42	9.8	2.12	9.5	4.05	2.06	-	-	0.05	0.015	Bal.	Blade	HITACHI Metals, Ltd.
TOMILLOY	0.06	21.4	8.2	9.3	3.0	0.3	0.96	-	-	-	0.003	Bal.	Combustor	MITSUBISHI

Fig. 4. U.S. delegates sprinkled among the growing Japanese superalloys community at the 1984 Japan-U.S.A. Seminar on Superalloys. U.S. delegates in front row--Don Muzyka (Cabot), Gern Maurer (SMC), Maury Gell (P&WA), John Tien (Columbia), Norm Stoloff (RPI), Alan Rosenstein (USAFOSR), Bruce MacDonald (USONR), Duane Ruckle (Garrett), Bob Jewett (Rocketdyne); 2nd row--Steve Antolovich (Georgia Tech), Frank Lemkey (UTRC); 3rd row--Fred Pettit (U. Pittsburgh); 4th row--Bob Miner (NASA); 5th row--Chain Liu (Oak Ridge) and Red Couts (Wyman-Gordon). The Japanese organizers include Prof. R. Tanaka (between Gell and Tien), Prof. M. Kikuchi (between Stoloff and Rosenstein), Dr. Y. Saiga (between MacDonald and Ruckle), and Dr. H. Susukida (left of Pettit).

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